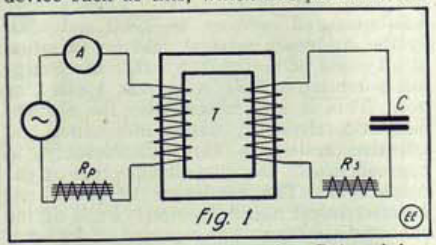
The Quenched Spark Gap

By CHAS. S. BALLANTINE, Radio Research Engineer

DURING the past five years the quenched gap has practically been adopted for commercial work by the various radio companies and seems to be giving complete satisfaction, both in regard to operating efficiency and the reduction of decrement of the radiated oscillations. A device such as this, which has past the test



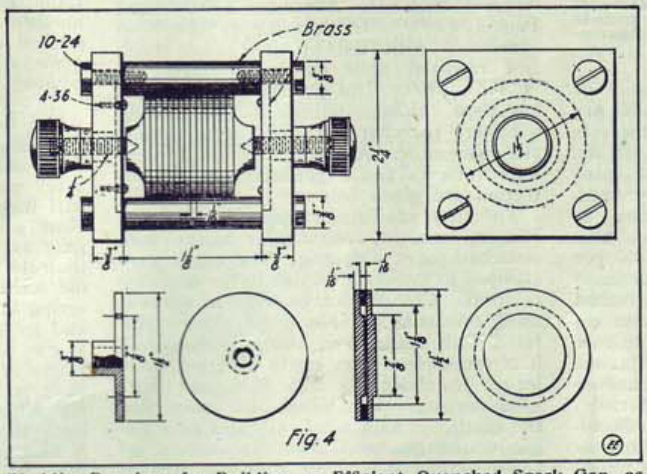
Arrangement of Apparatus for Determining Operating Characteristic of Resonance Transformer.

of actual operating conditions of all kinds, must certainly have sufficient merit to warrant its universal adoption.

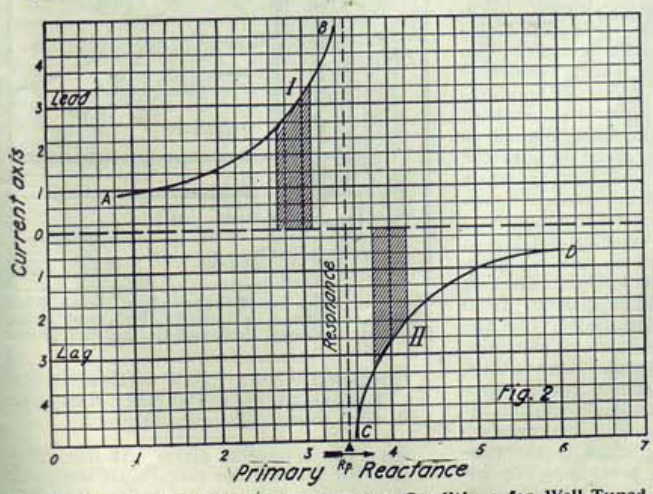
In amateur circles very few of these gaps are seen, principally because of the cost of their construction and on account of the fact that the few who have tried them have not made a sufficient study of their operating characteristics to attain the results that should be obtained, and hence have condemned them from the start. The expression of such an opinion, founded on nothing more than a cursory examination of their merits, of course is only a display of ignorance which is shown now and then by a few experimenters, but its effect has been quite extensive. The author knows several people who have never used a gap of this sort, and in fact have never seen one, but who from the start have exprest their opinion of it very forcibly. It is with the intention of helping to correct a few of these fallacies regarding the quenched gap that the following paragraphs have been attempted.

The quenched gap, as most of us know, consists of a number of very short gaps connected in series and made *air-tight*. During the period of the first few sparks across the gap, the oxygen of the air included in the gap *is burnt up*. What probably takes place is as follows: The atmosphere, composed of about 80 per cent nitrogen, 19 per cent oxygen and 1 per cent argon and other inert gases of this group, in the gap is decomposed by the spark into nitric acid from the nitrogen and water vapor, which unites with the metal of the gap to form *nitric oxid gas*. Under certain conditions other chemical reactions may take place, but the final result in any case is the reduction of pressure in the gap and the absence of oxygen in the succeeding discharges. Owing to the fact that all metals contain a certain amount of occluded gas, it is necessary to *season* the gap, by allowing it to operate continuously for a few hours before the note or tone finally becomes clear. If the gap leaks and air is constantly being admitted to the sparking chamber, its presence may be determined by the appearance of the sparking surface, which oxidizes rapidly and becomes covered with a black deposit.

If this occurs, the gap should be thoroly cleaned with alcohol and a piece of crocus cloth or very fine sand paper, taking care to remove all fine particles of foreign matter before reassembling. The gaskets should be examined and cleaned and if they appear to be perfect, the gap may be reassembled, using a little more pressure to bind the plates together. If the gap still continues to leak, replace the gaskets and test it again. Further failure would seem to indicate that the gap was mechanically defective.

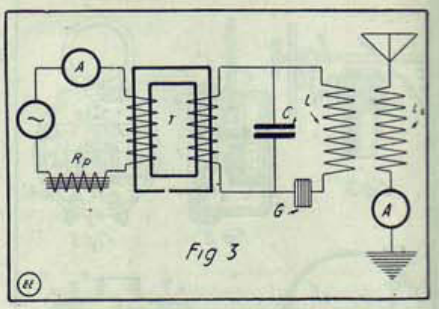


Working Drawings for Building an Efficient Quenched Spark Gap, as Described by Mr. Ballantine.



Graphs Showing Off-Resonance Operating Conditions for Well-Tuned Quenched Spark Set.

In regard to the engineering aspects of quenched gap operation much has been written, and it will be only necessary to review a few of the basic principles here. In the operation of this gap the condenser capacity and phase relations of the various currents in the transformer are of great importance. Generally the amateur must accept his current as he receives it, when the supply is drawn from the city mains. In cases where the generator is located near the apparatus, some control may be had over its operation, and consequently the adjustments for good working conditions are very much simplified. It is regrettable that this condition is an exception rather than the general rule. In the following discussion it will be assumed that the current supply is drawn from the city mains, and that the phase



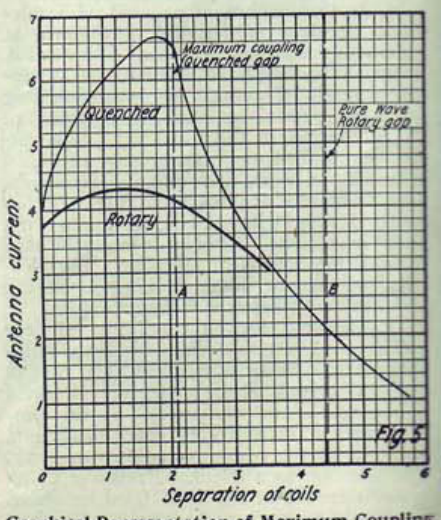
Connections for Quenched Spark Radio Transmitter, as Described in Present Article.

relations of the currents reaching the primary circuit are unknown. The author has used the following method of adjusting the transmitter for some time, with excellent results:

To begin with, it would be well to point out that the method described is one that can be applied to any transmitter, but is particularly useful when the quenched gap is employed, as it is absolutely necessary to have perfect resonance conditions in all circuits with this gap. Otherwise the inferior results referred to in the opening paragraph will probably be obtained.

The apparatus indicated in Fig. 1 are arranged as follows: T represents the low frequency transformer, preferably of the closed core type. An ammeter is connected in the primary circuit as shown at A. The reactance Rp is inserted in the primary. The secondary reactance shown at Rs may be omitted, as its effect on the circuit is slight as compared with that of Rp. This may be seen from the vectors of the ideal transformer. Further, any resistance inserted in the primary side of transformer has an effect equivalent to

(*Continued on page 855*)



Graphical Representation of Maximum Coupling Permissible for Typical "Quenched" and "Rotary" Gaps.

JANUARY MEETING OF THE A.I.E.E.

The American Institute of Electrical Engineers held their 328th meeting on January twelfth under the auspices of the Pittsburgh Section of the Traction and Transportation Committee at the Fort Pitt Hotel, Pittsburgh, Pa.

An interesting paper entitled "Regenerative Braking of Electric Vehicles" was presented by R. E. Hellmund of the Westinghouse Electric and Manufacturing Company. This paper presented an exhaustive study of regenerative control as applicable to the various systems of electrical railways; and in view of the wide possibilities which exist for successful regeneration, the subject of regenerative braking is now rapidly assuming considerable commercial importance. It possesses many practical advantages in electric railway work and for heavy railroads, as well as in various other fields, such as steel mills, etc., which cause this subject to be of particular interest to electrical engineers engaged in railway work and other industrial applications of electric power.

THE QUENCHED SPARK GAP.

(*Continued from page 815*)

the same amount inserted in the secondary, circuit, multiplied by the square of the ratio of transformation. The opposite holds true in the case of capacity, which is transferred from one circuit to the other by dividing by the ratio squared. Reactance, as stated before, behaves like resistance. Our reactance adjustments can be most conveniently made in the primary side of the transformer.

The condenser C is connected across the secondary terminals of the transformer without any other apparatus. Its capacity may be roughly determined by the usual power relations, assuming the voltage is known, and should be made adjustable.

When the apparatus has been arranged as shown, the primary mains are connected to the transformer and the current indicated on the ammeter noted when Rp has been adjusted to maximum indication. The capacity at C is then increased until the maximum is again obtained and its value noted. This procedure is gone thru for the different capacities and the corresponding ammeter readings entered in a table. Care should be taken that the condenser capacity does not exceed the limiting value set by the equation:—

$$C = \frac{\lambda^2}{3552L};$$

where L represents the primary radio inductance for the wave length to be used. Any excess of this value would not permit of sufficient inductance in the primary of the oscillation transformer to permit of efficient energy transfer to the antenna. The condenser capacity which gives the largest ammeter reading at resonance should be the one used. If the primary of the transformer is provided with taps for power variation, each tap should be measured in terms of resonant condenser capacity and tabulated for reference. It is possible that the reactance in the primary of the transformer of the closed core type will not be needed for some adjustments, but the condensance of the total circuit should be increased so that the adjustments may be made by this means, as greater flexibility is then obtained.

It will be noted that the writer has referred to the closed core transformer as being the best for quenched gap work. This question of difference between the two types of transformer has been disputed for several years and various opinions have

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been exprest. The reasons why the author has suggested the use of the closed core type are as follows: In favor of the open core type, it might be said that it possesses the desirable high leakage characteristic and is simple, both in design and construction. The closed core type requires less copper and iron for a given output, and consequently the losses are smaller and it is more efficient. The relative space taken up by the two forms favors the closed core type also. It will be seen that the closed core instrument is to be preferred. However, the open core type can be used, provided a suitable reactance is inserted in the primary to compensate for the leakage reactance of the other type. This is in addition to the adjusting reactance used in the preceding experiment, and can be incorporated in the adjusting reactance itself.

It has been the experience of various engineers working with the quenched gap that a *detuning* of the transformer circuit about 15 per cent off the resonant frequency just determined was desirable in order to obtain a clear note. This may be done later when the gap is put in operation by readjusting the reactance in the primary. An explanation of this detuning process as given by a well-known engineer is somewhat as follows:

Referring to Fig. 2, which represents the variation and phase relations of the current with the various reactance adjustments as abscissae, the heavy dotted line drawn parallel to the Rp axis indicates the zero phase axis. Above this line capacity predominates and the primary current leads, while below it the current lags. It will be observed that the current curve has an asymptote on an axis at right angles to Rp at the resonance point. In other words the current at this point reaches a high value, and is limited only by the resistance of the circuit. This would indicate that the point of exact resonance does not represent a safe working condition owing to the excessive current obtained. Of course this could be controlled by means of resistance, but this would reduce the efficiency of the apparatus and it will be found better to detune from the resonant frequency. The shaded portions of Fig. 2 show the operating regions after this is done.

The question now arises as to the difference between these regions. It will generally be found that operation in the region marked II will give the best results, from the standpoint of spark clarity. From A to B the current will lead, causing a rise of generator voltage because of the rapid reduction of initial gap resistance, due to the fact that currents in this phase relationship cause the armature reaction to aid with greater extent the generated E.M.F. In the region C to D the opposite holds true, *i.e.*, that the voltage will fall as the resistance of the gap drops, resulting in practically a uniform current thru the gap, and a pure note. This is probably the reason why it is better to work above the resonant point rather than on or below it. Experiment under the actual conditions is the only means by which the exact operating point may be determined.

Referring to Fig. 3, it will be seen that the quenched gap G and inductances L_1 and L_2 of the radio circuit have been connected in, and coupled to the antenna circuit. Previously, however, the two radio frequency circuits are tuned to resonance and the coupling adjusted until the two emitted waves lie close together. Call this the critical coupling. Now, using all the gaps at hand, the mains are connected to the primary and the set operated. Allow the gap to operate for about five to ten minutes, in order to complete the chemical reduction in the sparking chamber.

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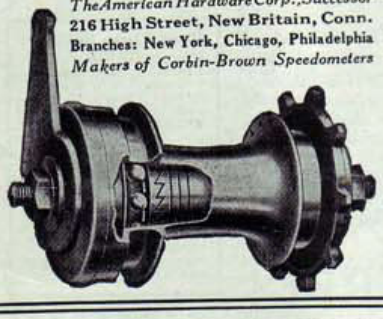

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ure in a great many quenched gaps on account of leakage. The writer has tried nearly everything in the line of insulating materials and has found that ordinary cardboard, impregnated with an insulating varnish containing rubber, gave the best results and at the same time was much more economical than any of the others. The number to use in each gap of course depends on the thickness of the material employed, and the total voltage to be used in the gap, and can be determined experimentally. In mounting the gap apply sufficient pressure but do not overtax the materials supporting it. The elastic limit of the materials shown in the drawing is great enough, provided reasonable care is exercised in assembling the gap and clamping the plates.

If the note of the gap is not clear after making the adjustments according to the preceding paragraphs, either the gap may be leaking, is too short, or the condensers or the gap may be *brushing*. There should be absolutely no brush discharge around apparatus using a quenched gap. When this condition does exist, it will invariably be found impossible to thoroly clear the note.

The coupling adjustment with the quenched gap is a delicate one and should be made carefully.

In Fig. 5 is shown graphically the general effect of the coupling adjustment on the radiated energy. These curves for the case of a quenched gap and synchronous rotary gap were obtained with the apparatus shown in Fig. 3. The sharp rise to the maximum in the case of the quenched gap is clearly shown. Another point of interest is the increased radiation over that obtained with the rotary. The maximum radiation obtained with the synchronous rotary gap was nearly 4.4 amperes, while that of the quenched transmitter was 50 per cent higher, 6.7 amperes. Decrement readings were made for each coupling adjustment to determine the boundary conditions of operation in order to keep the radiation within the limits defined in the radio legislation. It was found that at about two inches coupling, the quenched gap radiated practically one wave, while for a *condition even approaching this* the coupling with the rotary gap had to be loosened to 4.5 in. This resulted in the antenna current dropping to about 2 amperes, which is very low compared with the 6.6 amperes obtained with the quenched gap.

It is at once apparent from a consideration of the above results that the quenched type of spark transmitter is appreciably more efficient in every respect.

TESTING HIGH VOLTAGES WITH SPARK GAPS.

(*Continued from page 822*)

tive air density should be taken from table below.

Values of relative air density and corre ponding values of the correction factor are tabulated below. It will be seen that for values above .9, the correction factor does not differ greatly from the relative air density.

The Spark-Over Voltage, for a given gap, decreases with decreasing barometric pressure and increasing temperature. This correction may be considerable at high altitudes.

The spacing at which it is necessary to set a gap to spark over at some required voltage, is found as follows: Divide the required voltage by the correction factor given in Table 4. A new voltage is thus obtained. The spacing on the standard curves obtained from Table 3, corresponding to this new voltage, is the required spacing.

The voltage at which a given gap sparks over is found by taking the voltage corres-

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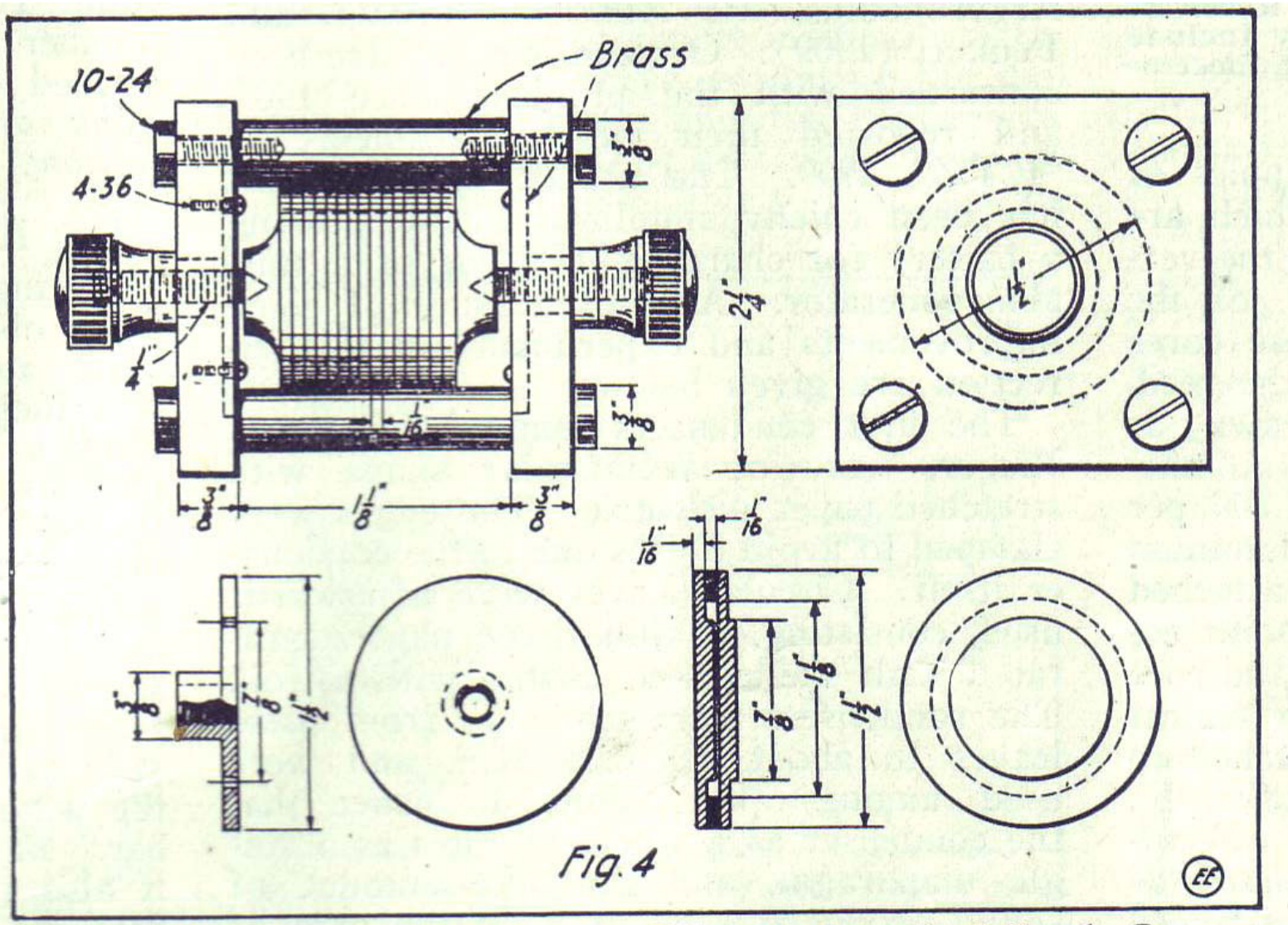

Fig. 4

Working Drawings for Building an Efficient Quenched Spark Gap, as Described by Mr. Ballantine.